Effect Of Material And Manufacturing Variations On MEAs Pressure Distribution

by

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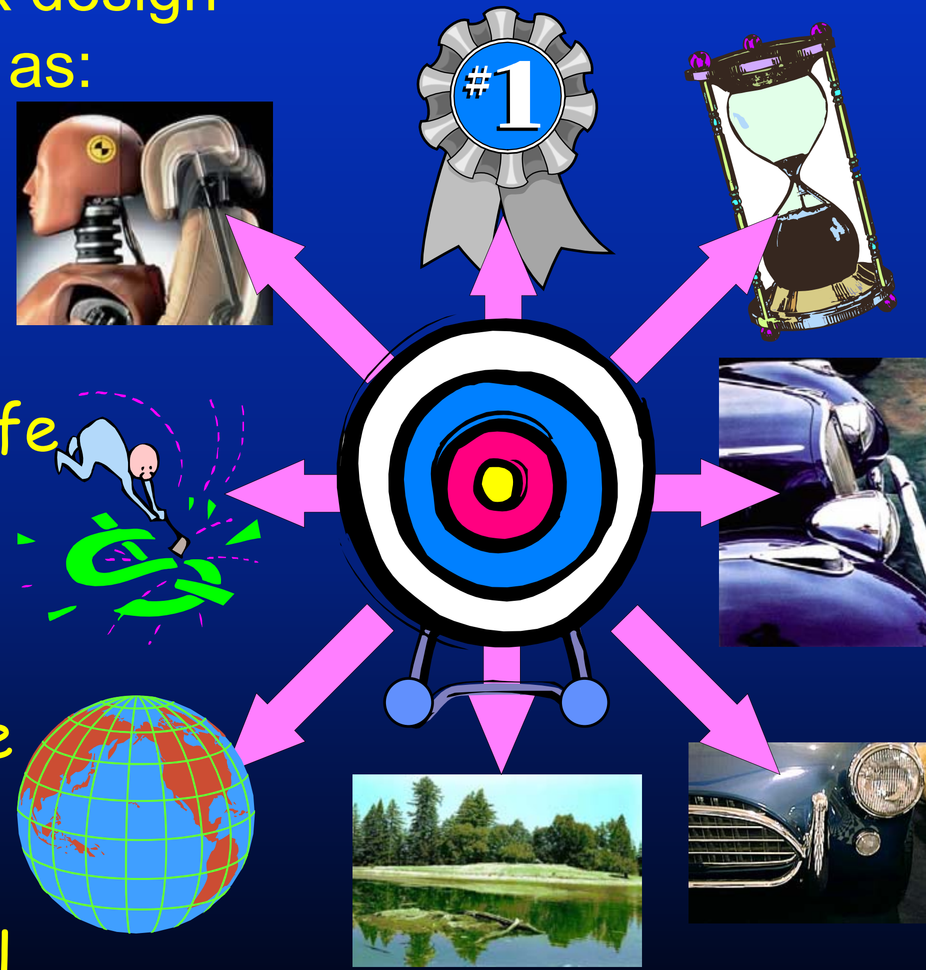
Contradicting Design Requirements

The need for innovative tools is apparent now more than ever as more complex design requirements are surfacing such as:

- Cost
- Performance & safety
- Quality
- Time to market & short life cycle
- Environmental impacts
- Aesthetics (wow, lust for the product, I got to have it ...)
- Major Changes in Industry's Business Model



Quality - Robust Design

- **Definition** of **Robust Design**:
  Deliver customer expectations at profitable cost regardless of:
  - customer usage
  - variation in manufacturing
  - variation in supplier
  - variation in distribution, delivery & installation
  - degradation over product life

- **Goals** of Robust Design (shift and squeeze)
  - Shift performance mean to the target value
  - Reduce product's performance variability

Statistical Design Performance Simulation?

" You 've got to be passionate lunatics about the quality issue …"

Jack Welch

"U.S. autos fight poor quality reputation …"

Joe Miller / The Detroit News

" Product quality requires managerial, technological and statistical concepts throughout all the major functions of the organization …"

Josheph M. Juran

Variation (thickness, properties, surface finish, loads, etc.) is … *THE ENEMY*

DOE, Six Sigma, Statistical FEA, Behavioral Modeling … *THE DEFENCE*

Improved Quality reduced Total Cost

Cost of Defect or Failure

- Lost Customers
- Liability (R&D)
- Recalls (production)
- Rework

Examples:

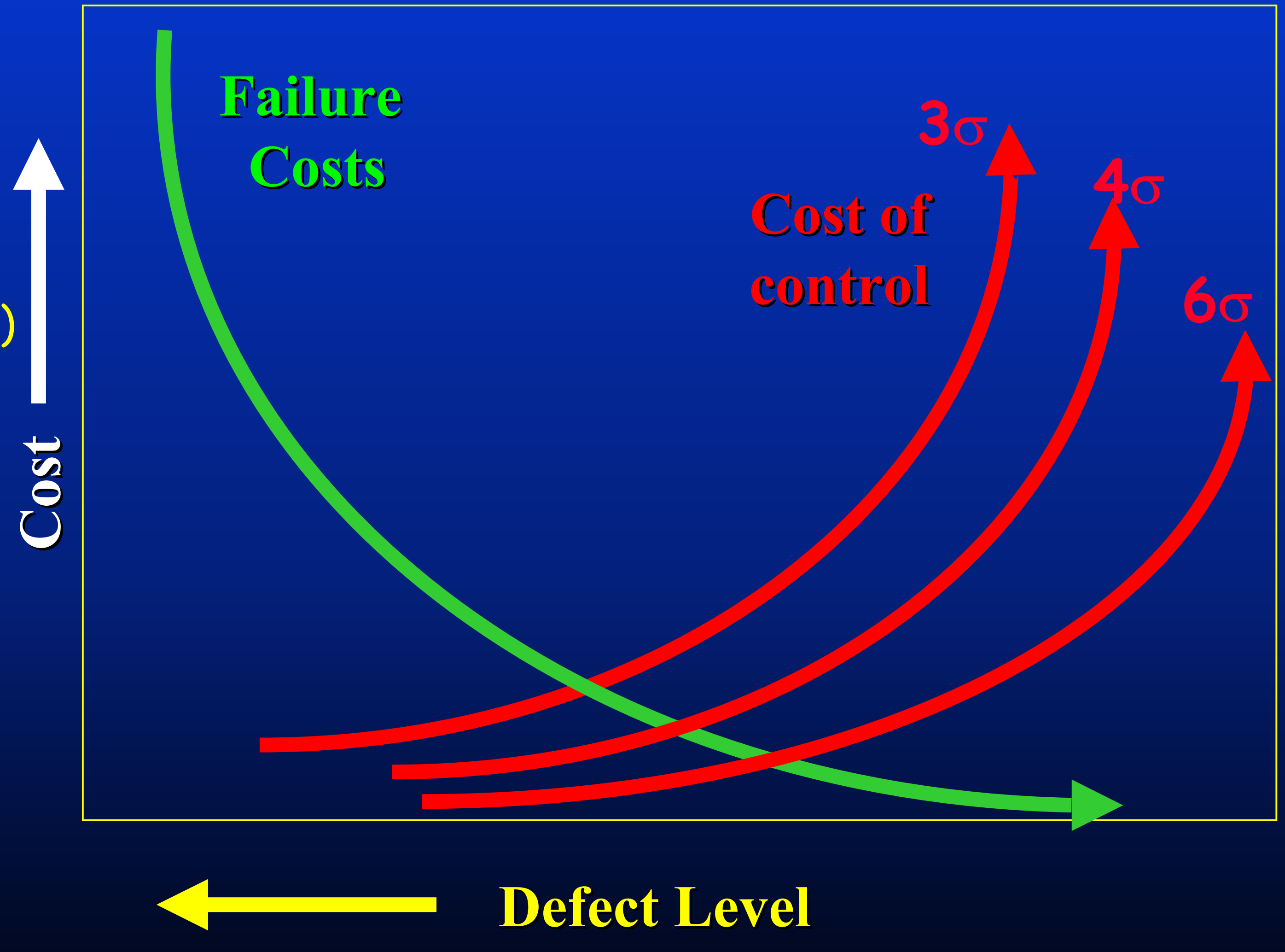
Titanic

Asbestos

Bhopal, India

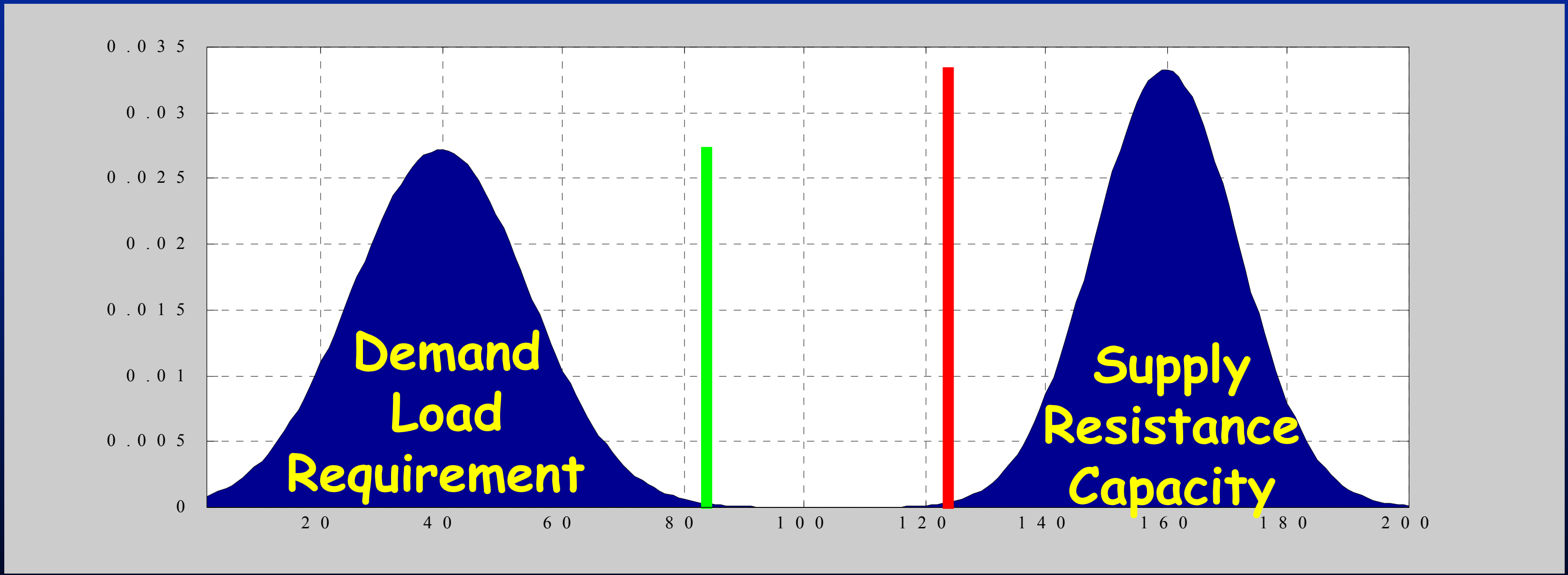
Tire

…



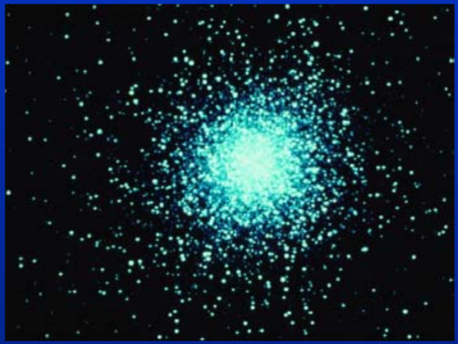
Traditional Deterministic Approach

- Accounts for uncertainties through the use of empirical Safety factors:
  - Are derived based on past experience
  - Do not guarantee safety or satisfactory performance
  - Do not provide sufficient information to achieve optimal use of available resources



Noise & Control Parameters

- Noise parameters:
  Factors that are beyond the control of the designer or too expensive to control or change
  - material property variability
  - manufacturing process limitations
  - environment temperature & humidity
  - component degradation with time
  - …

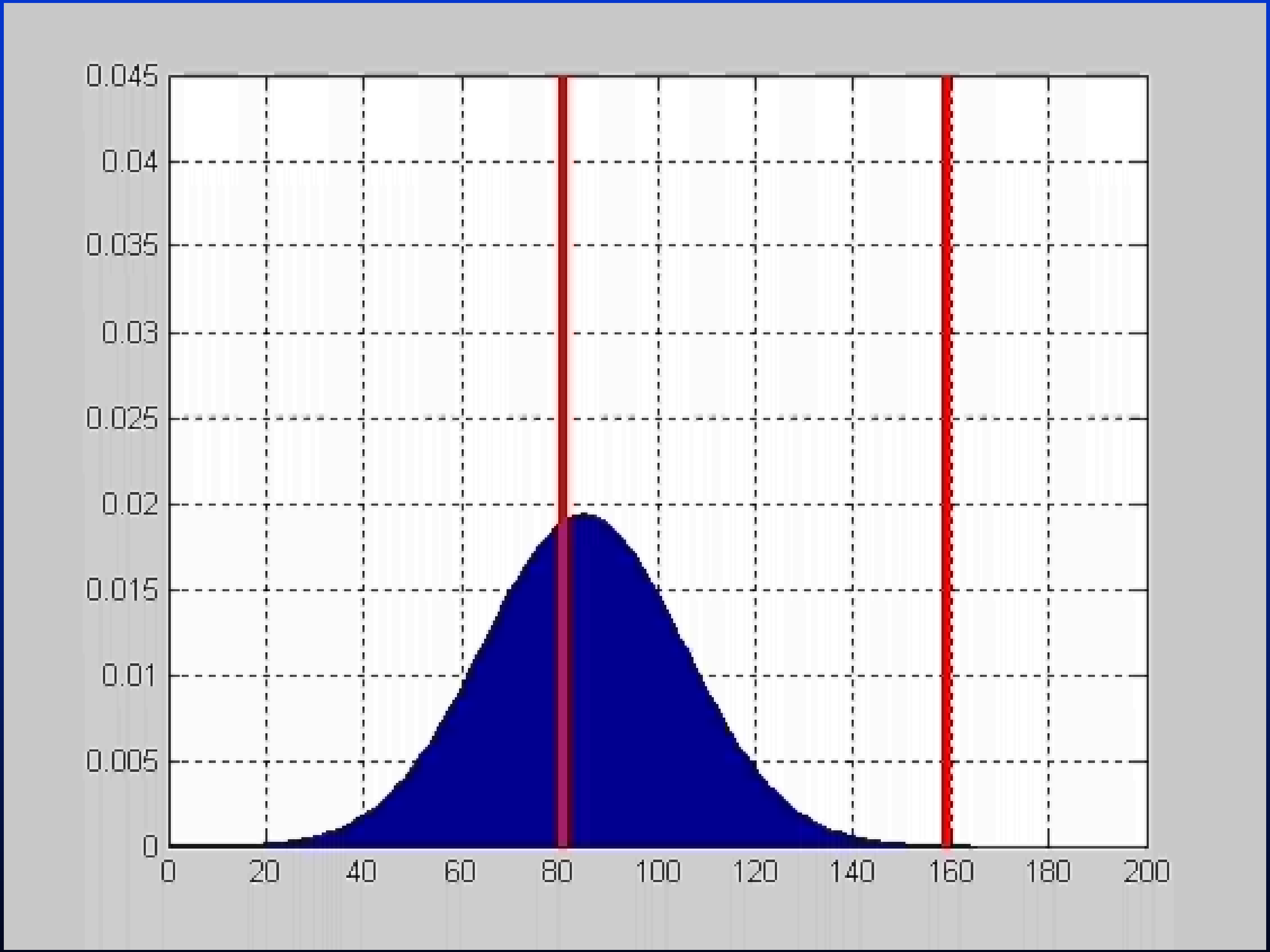


- Control Parameters:
  Factors that the designer can control
  - geometric design variables
  - material selections
  - design configurations
  - manufacturing process settings
  - …

Tools for Robust Design

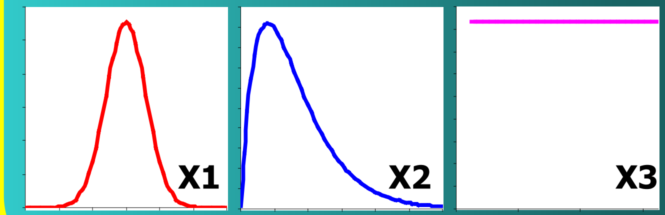
- Design Of Experiments
  - Exploits nonlinearities and interactions between noise & control parameters to reduce product performance variability
  - full factorial, fractional factorial, Monte-Carlo, LHC
- Response Surface Methods
  - Central Composite Design
  - Box-Behnken Design
- 6-sigma design
  - Identifying & qualifying causes of variation
  - Centering performance on specification target
  - Achieving Six Sigma level robustness on the key product performance characteristics with respect to the quantified variation

Shift and Squeeze



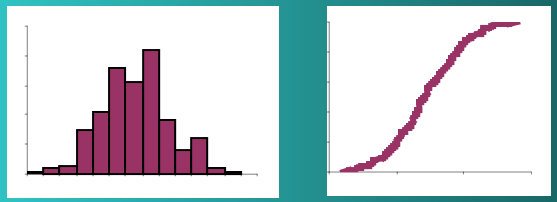
Statistical Design Performance Simulation

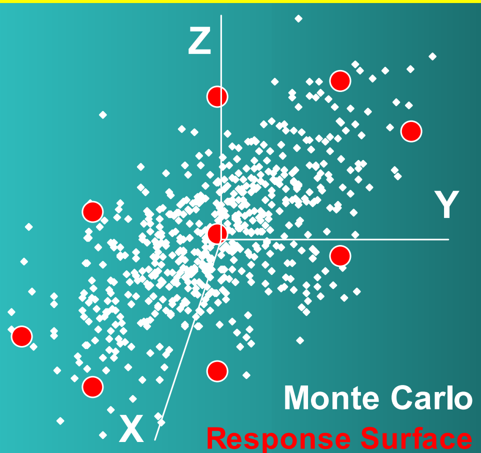
Simulation of input parameters (material, thickness, bolt load, …)



PDS

Statistical analysis of output parameters (stress, fatigue life, …)

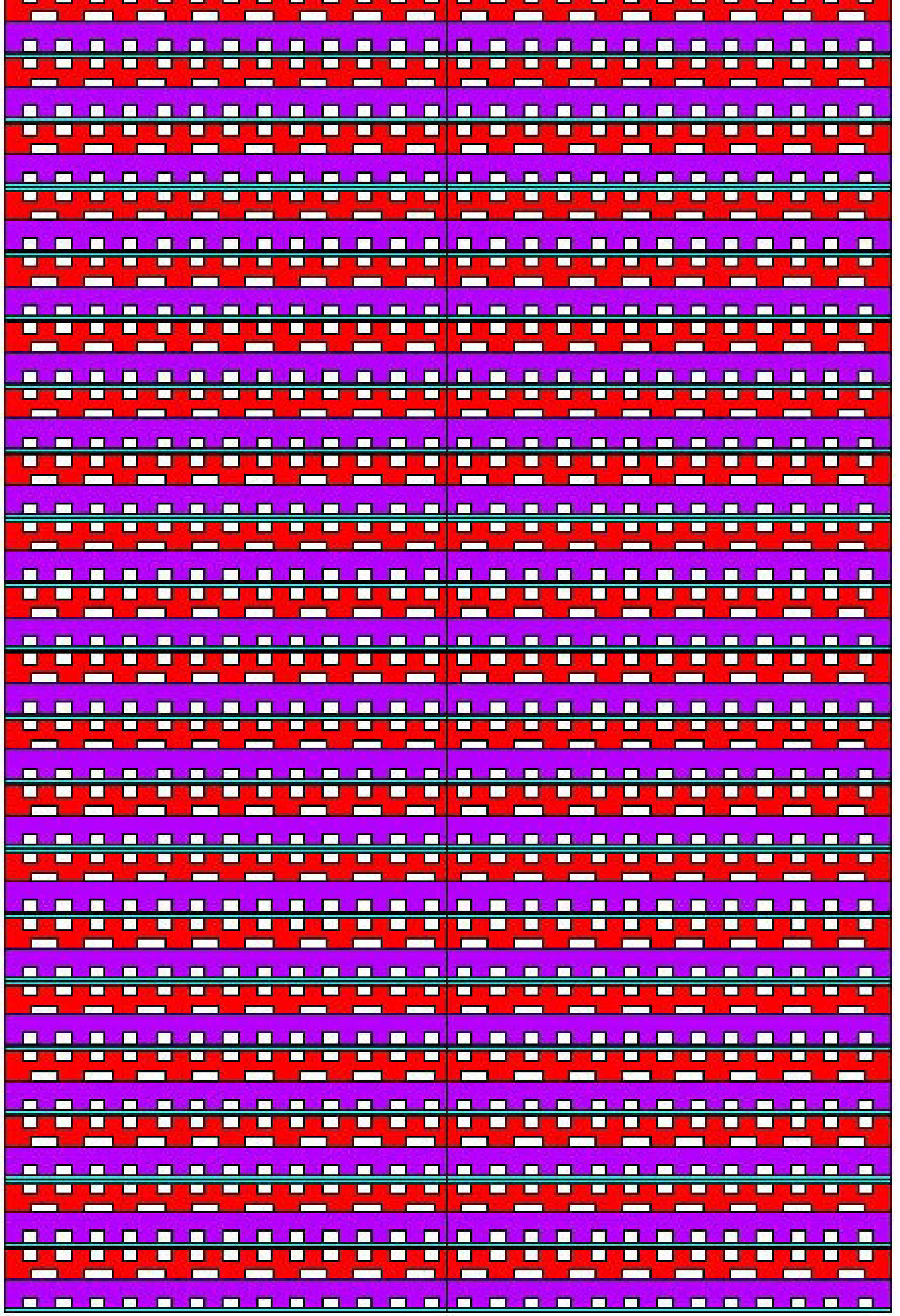


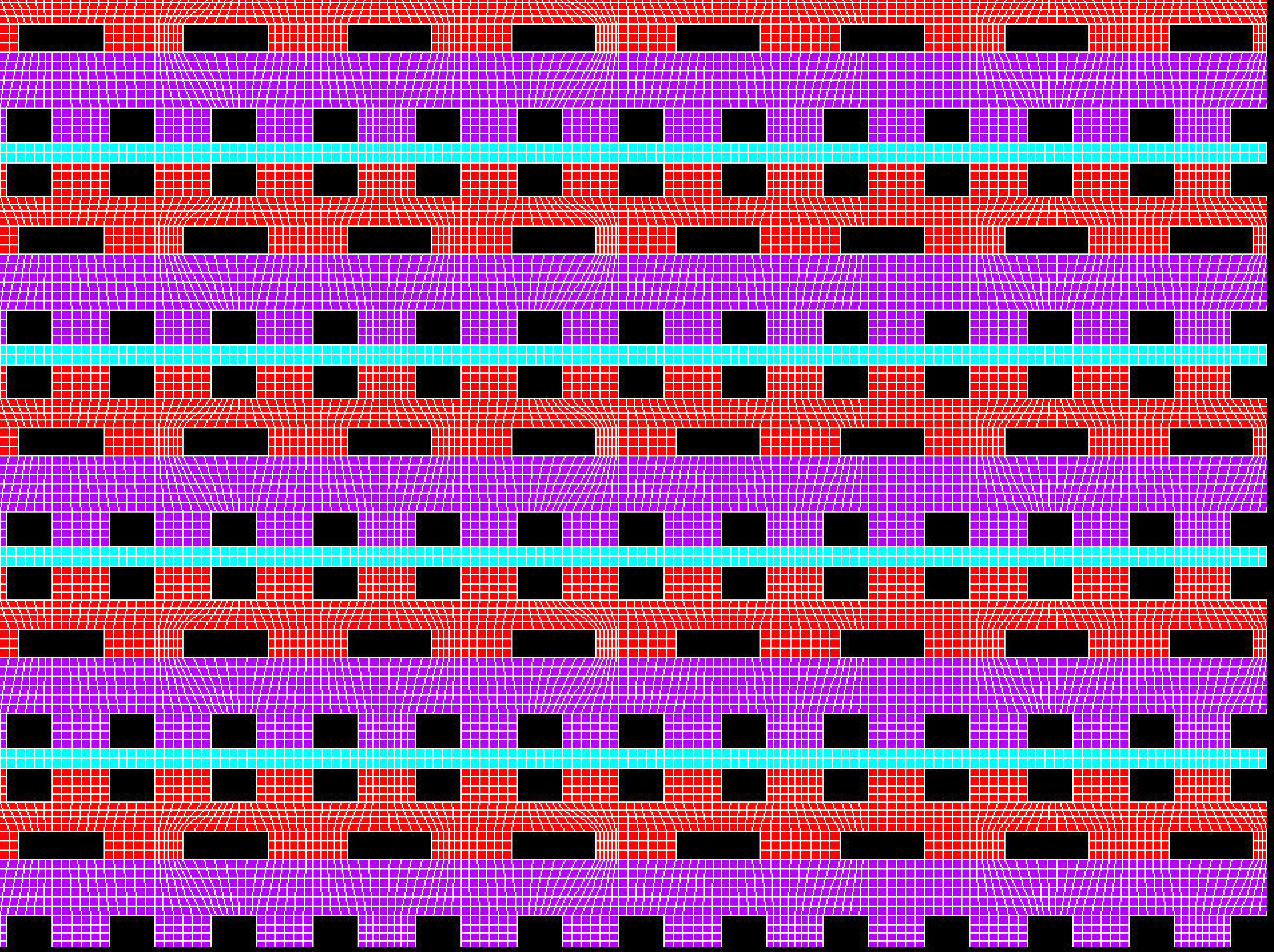


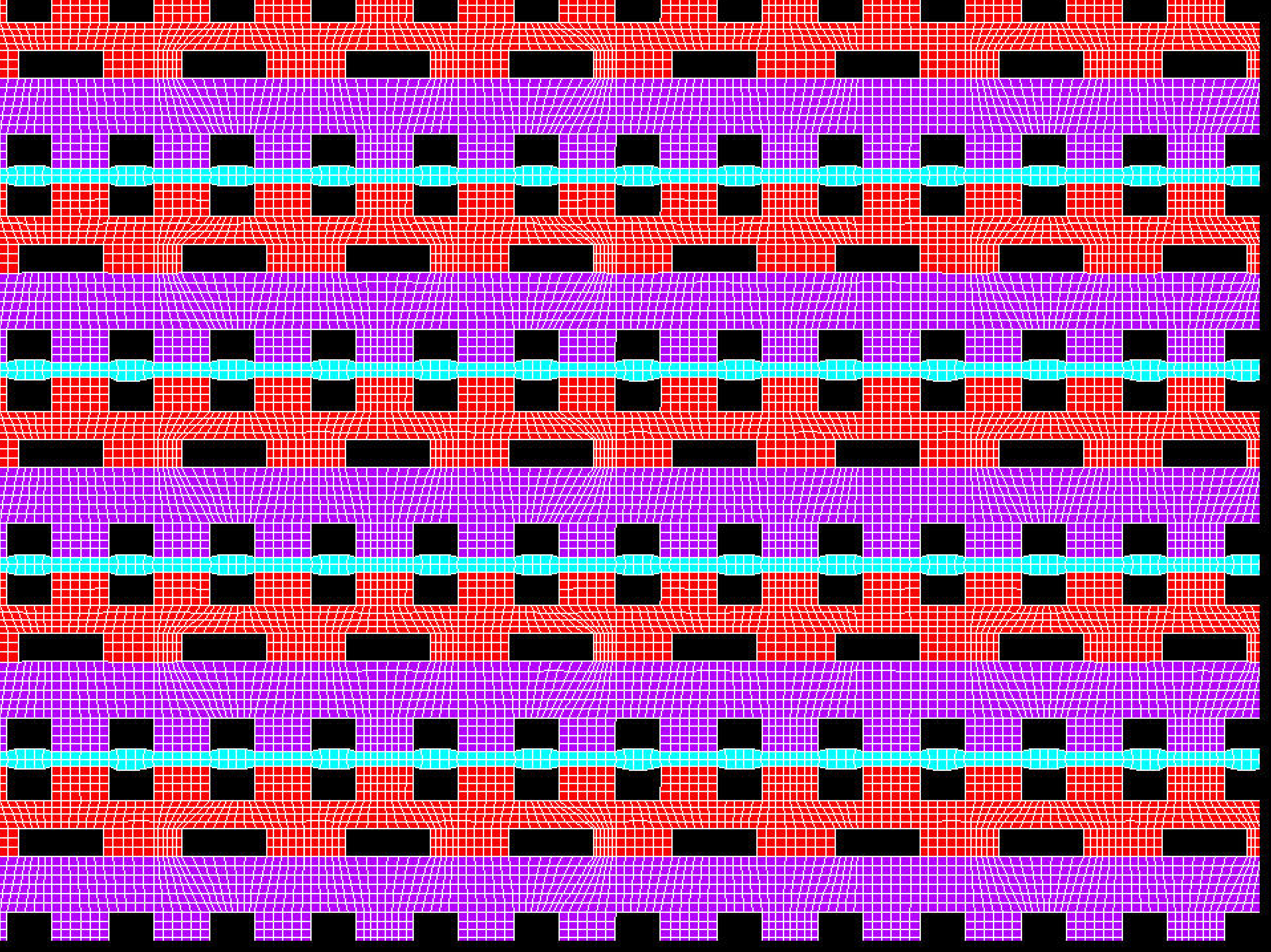
- **Over-design is avoided**
  (not "as planned", "as is" or the "worst design")
- **Weight Reduction**
- **Six sigma quality**

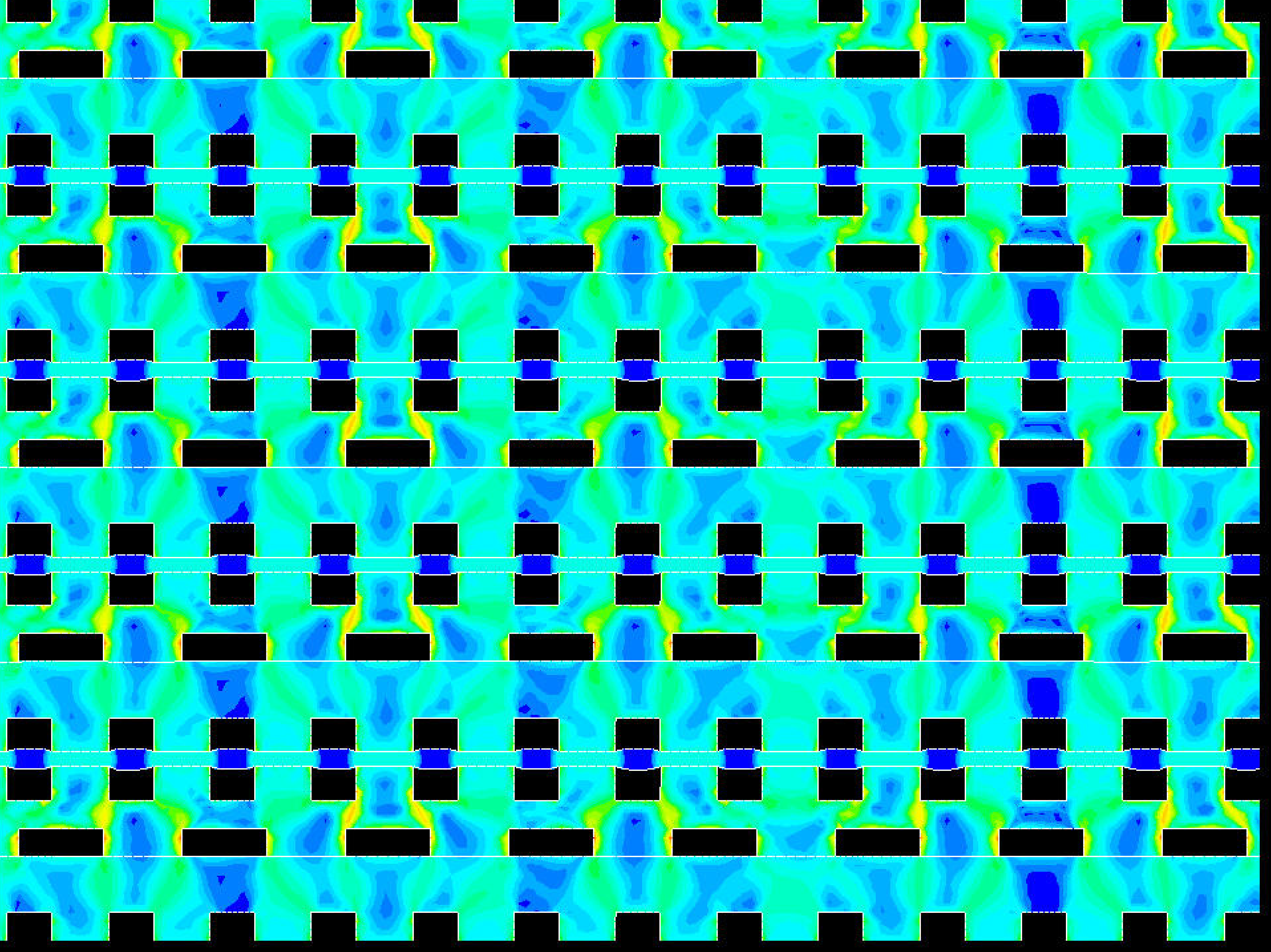
Fuel Cell Stack Model

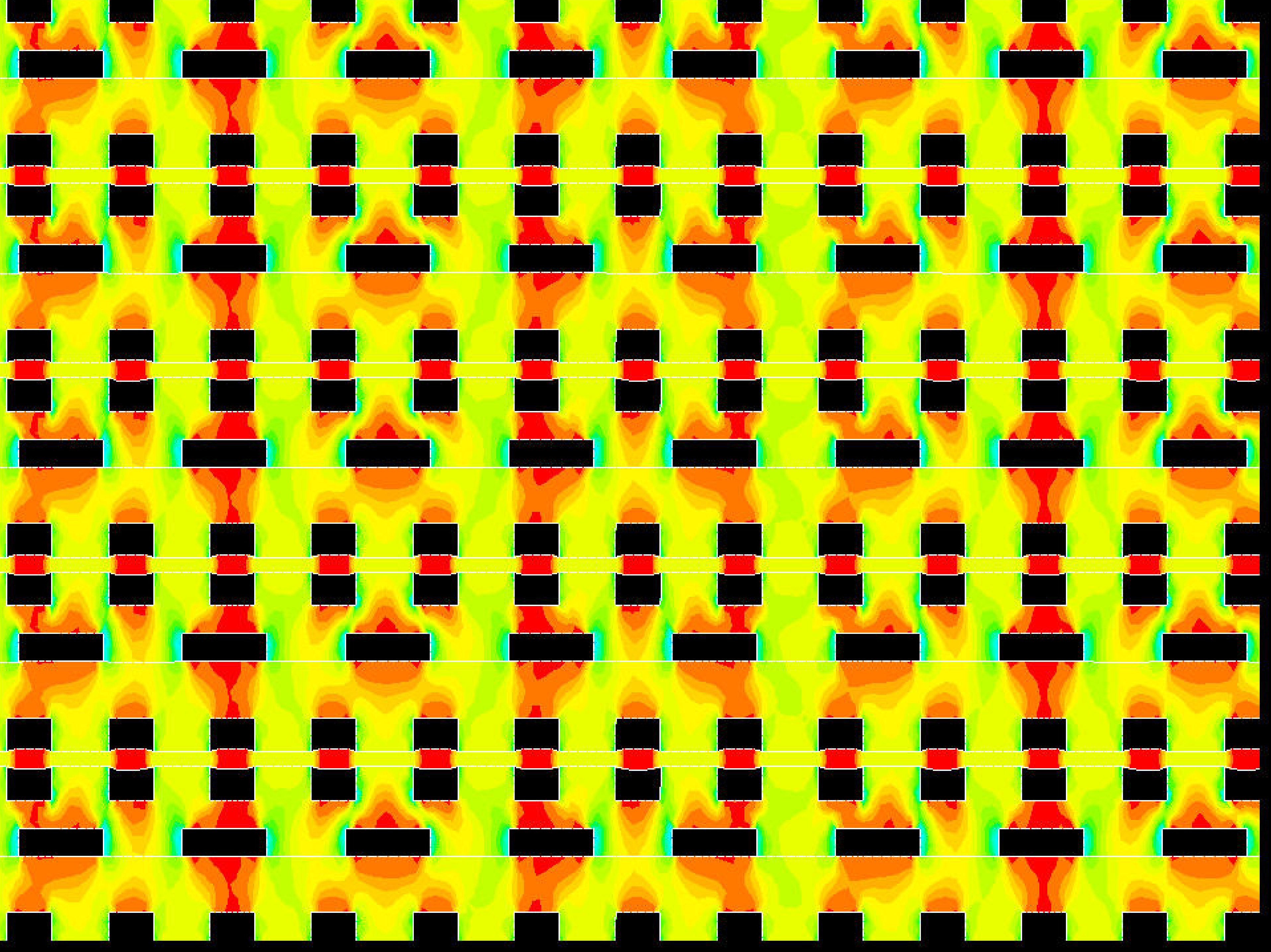
- Parametric
  - Dimensions
  - Material Properties
  - Loading
  - Discretization
  - Cell number
- Deterministic
  - For a set of input variables obtain one set of output variables
- Automatic
  - Read input parameter file
  - Perform Analysis
  - Generate Response variable file





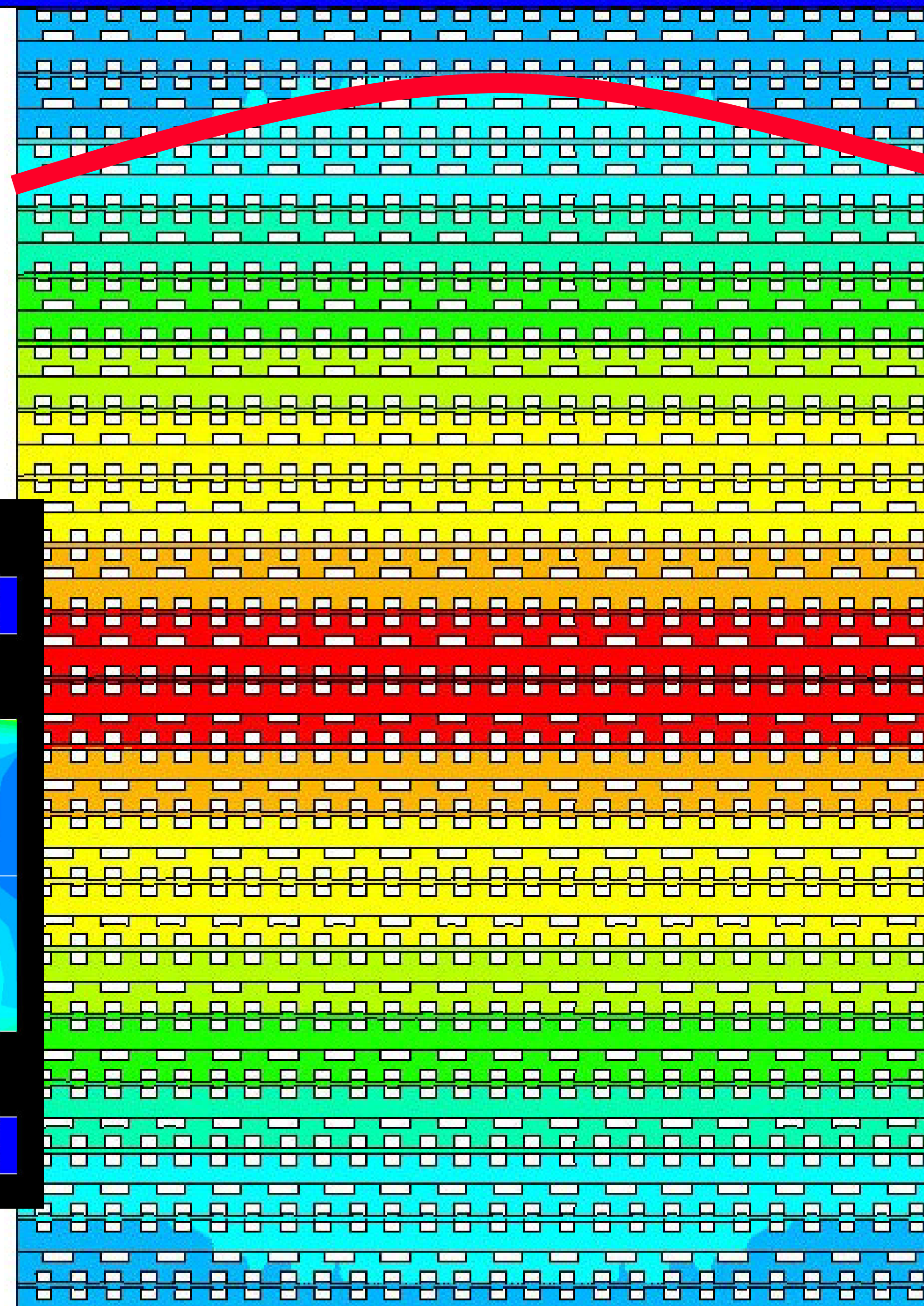


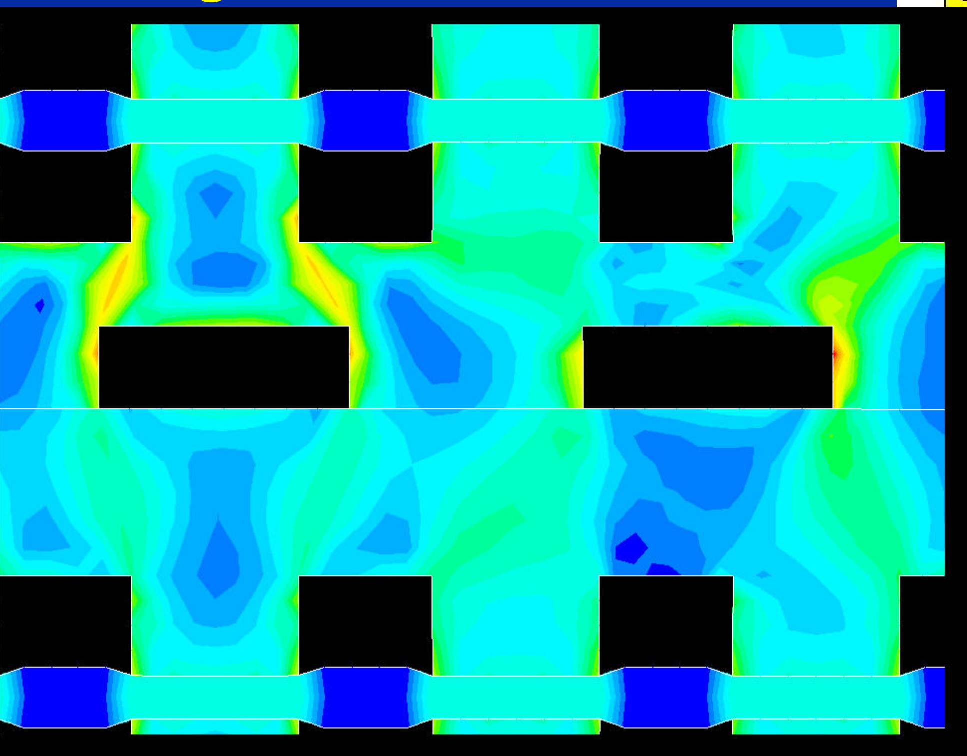




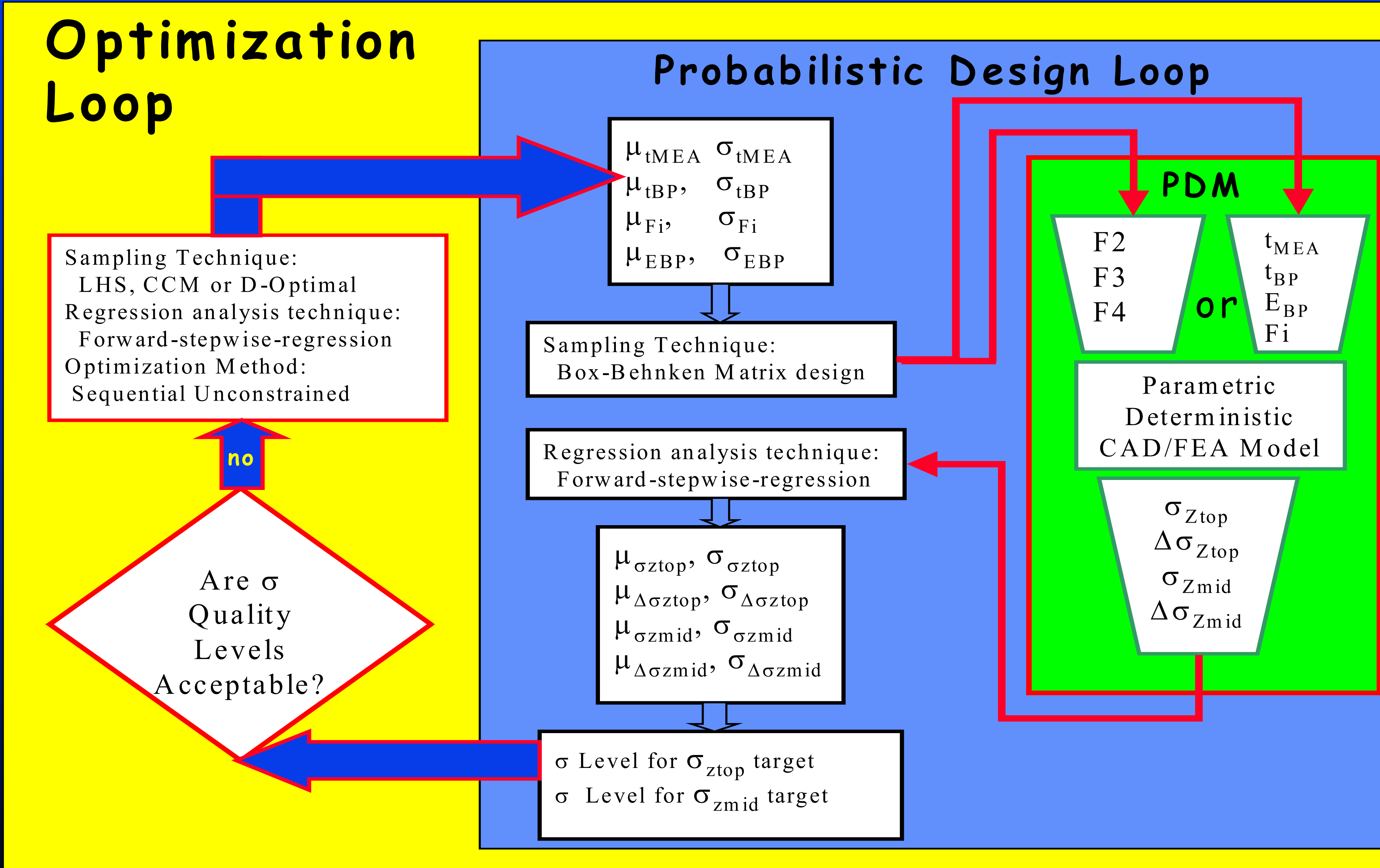
Edge effect

Only the first few MEAs at the top and bottom of the stack experience the higher stress level (compliance of "soft goods"





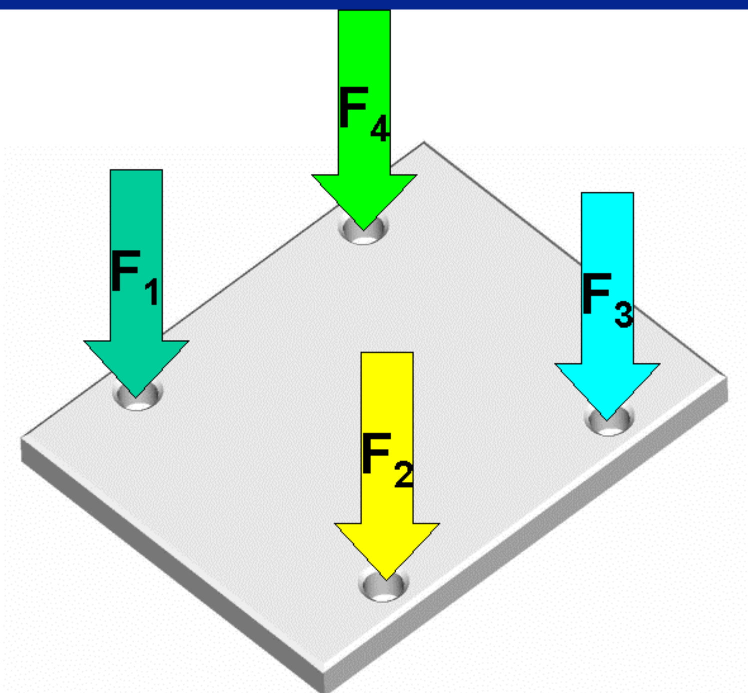
Workflow for Robust Optimization

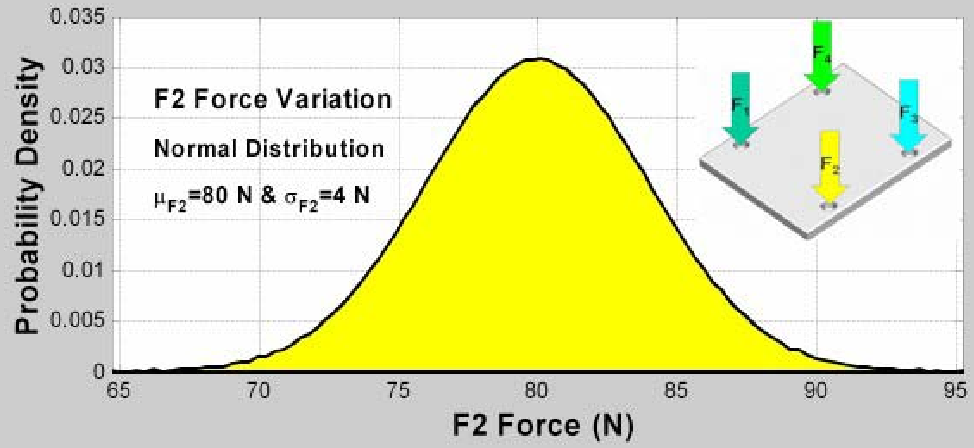


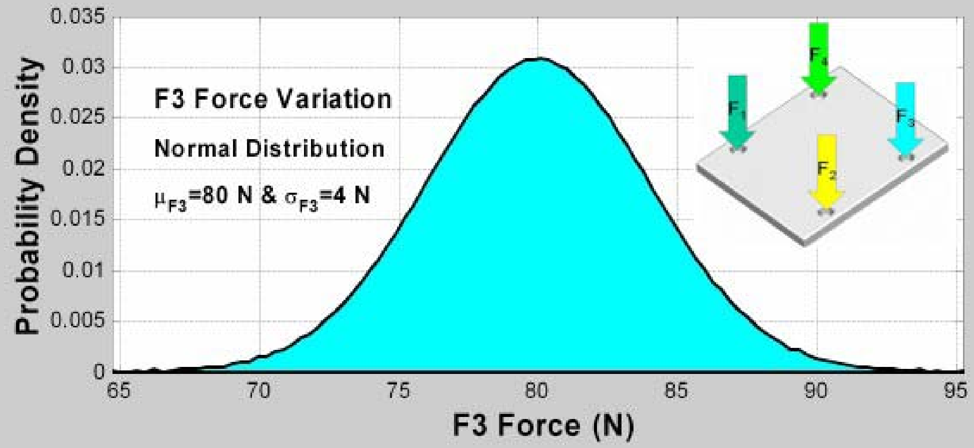
Inputs with Variation A

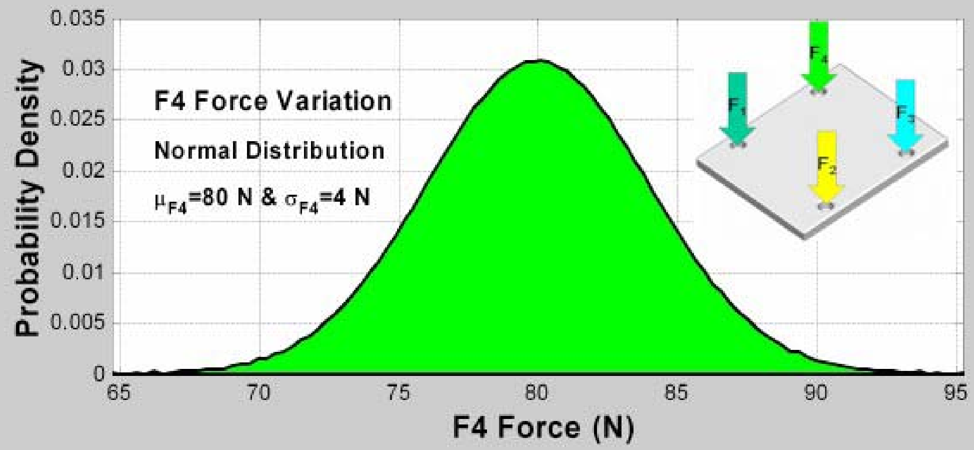
- Magnitude of Bolt Forces
- F1 Constant
- F2, F3 & F4 have variation with mean and standard deviation values

  μ_{Fi}, and σ_{Fi}



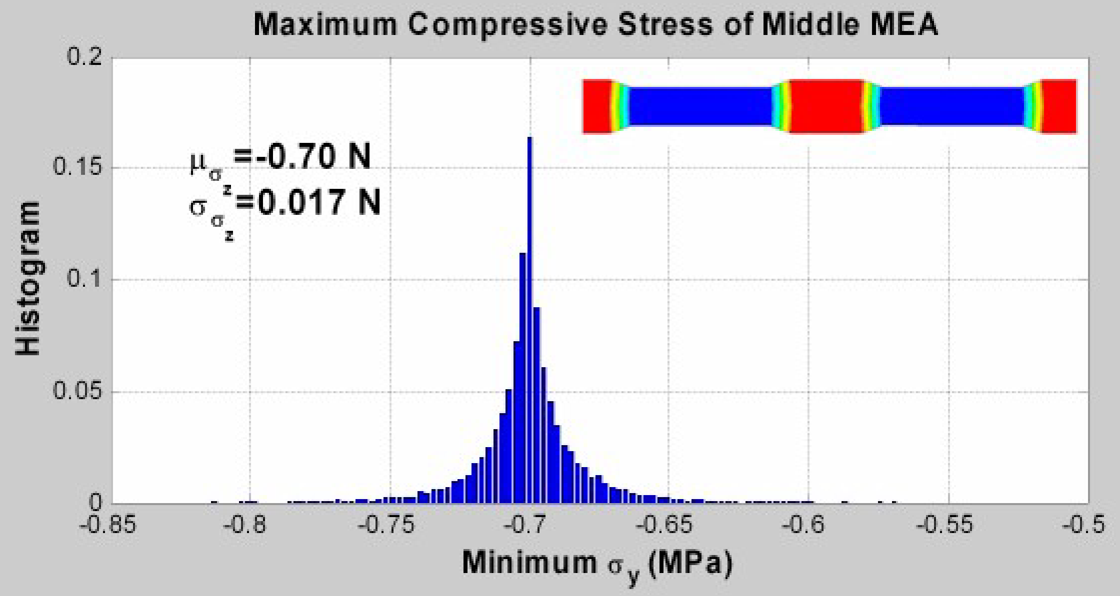


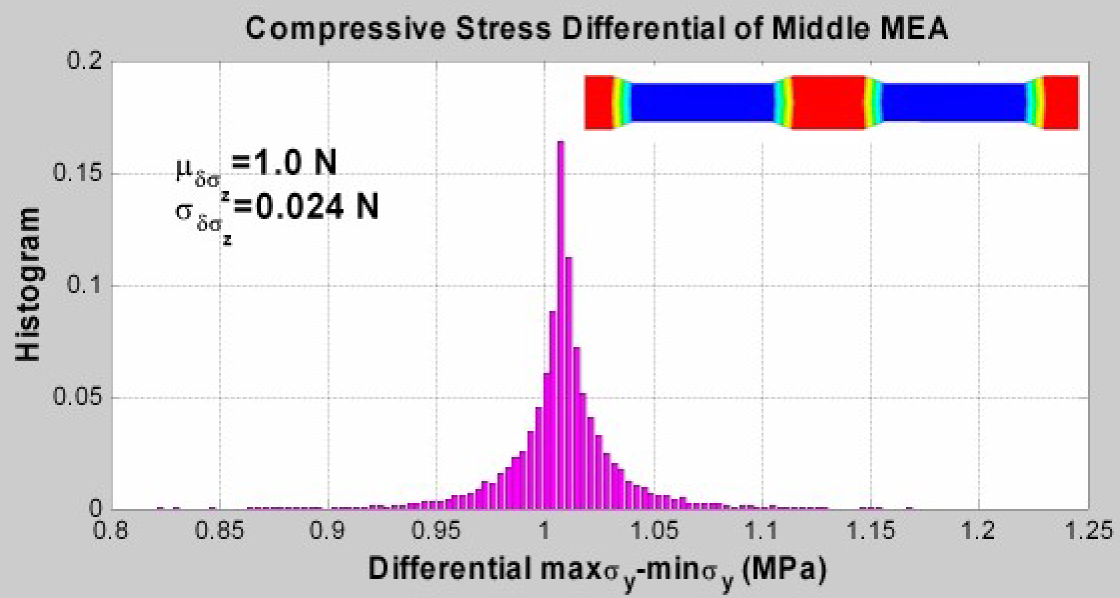




Outputs A

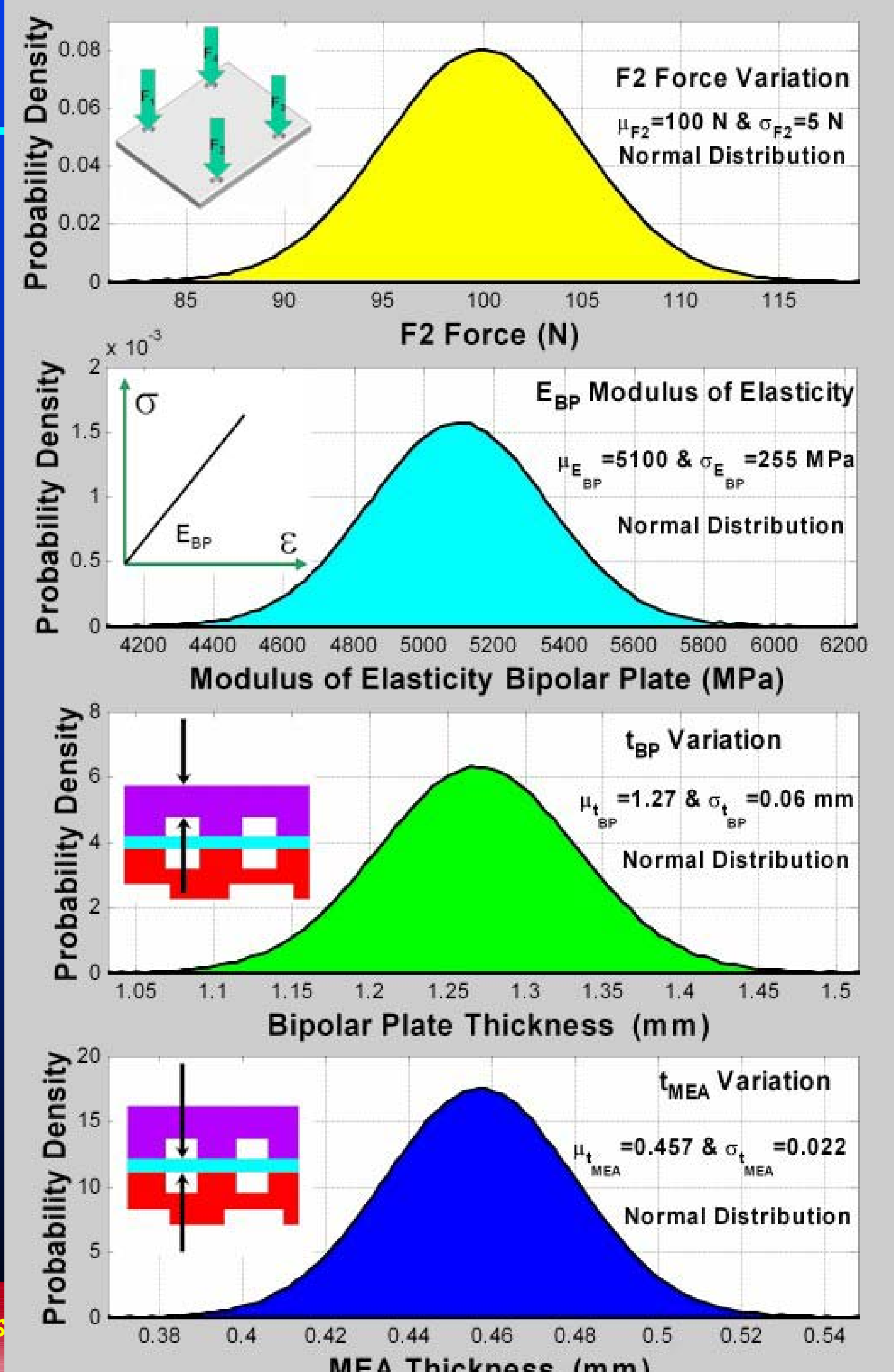
- SMART Attributes
  - Simple
  - Measurable
  - Agree to
  - Reasonable
  - Time-based
- Outputs – variation
  - max compressive stress
  - Max differential of compressive stress
- Four output parameters:
  - $\mu_{\sigma max}$, $\mu_{d\sigma max}$
  - $\sigma_{\sigma max}$, $\sigma_{d\sigma max}$



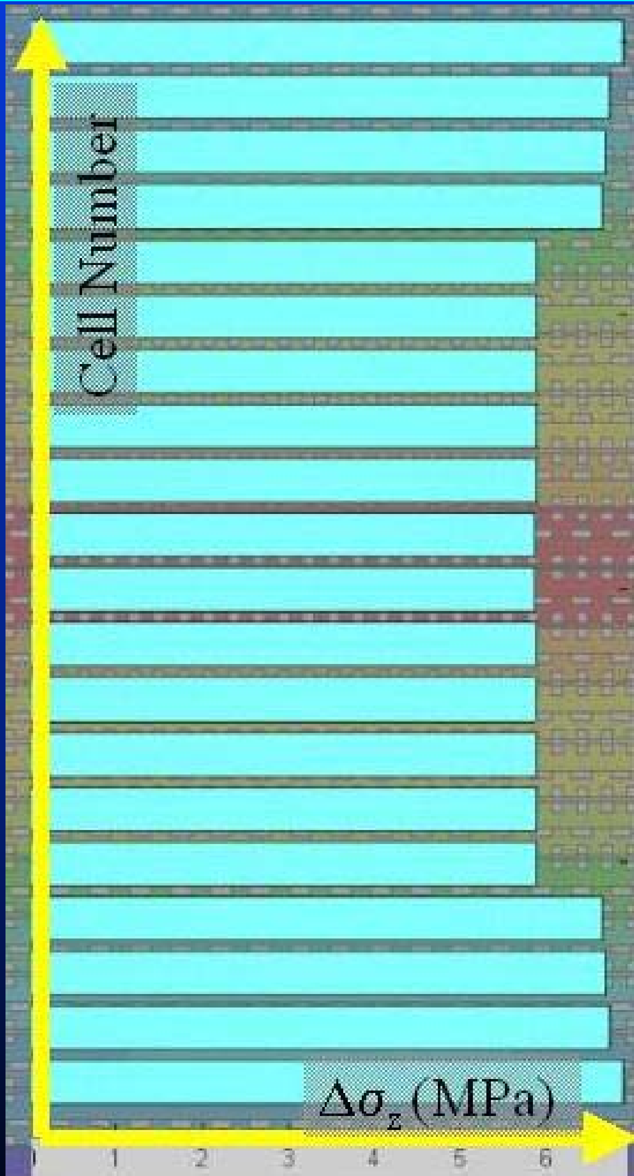


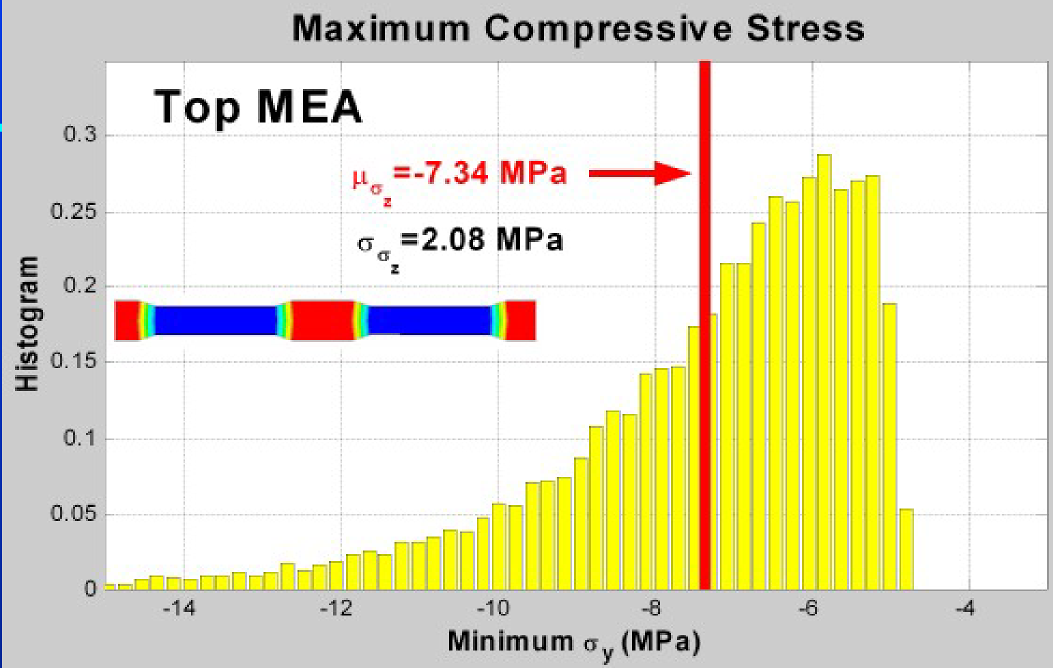
Input Case B

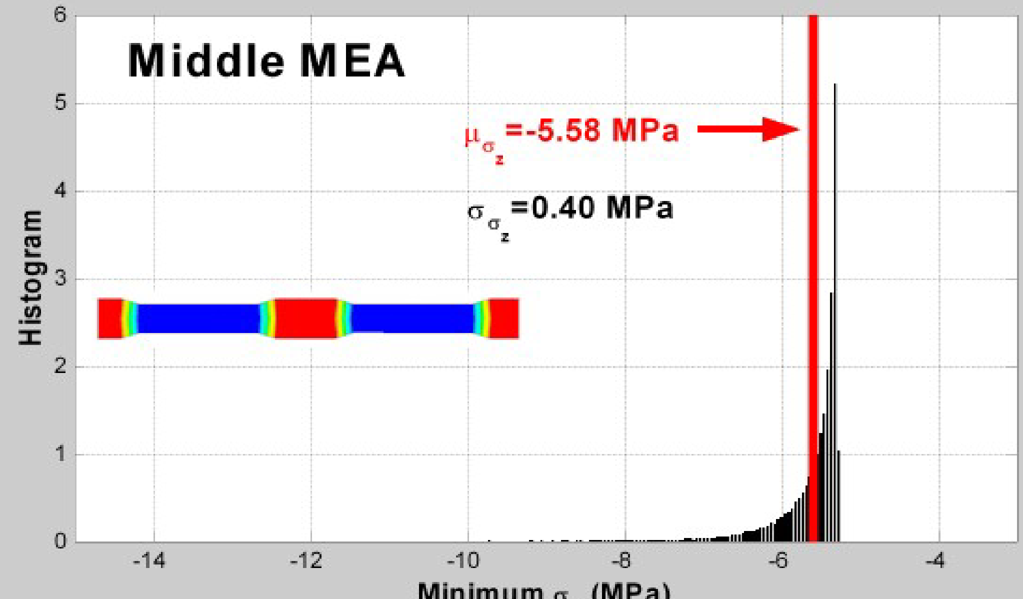
- Bolt Load
- Modulus of Elasticity
- Bipolar Plate thickness
- MEA thickness



Output Case B



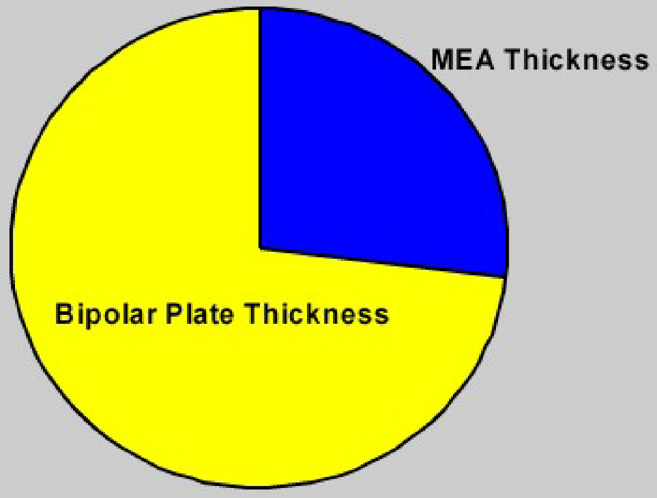




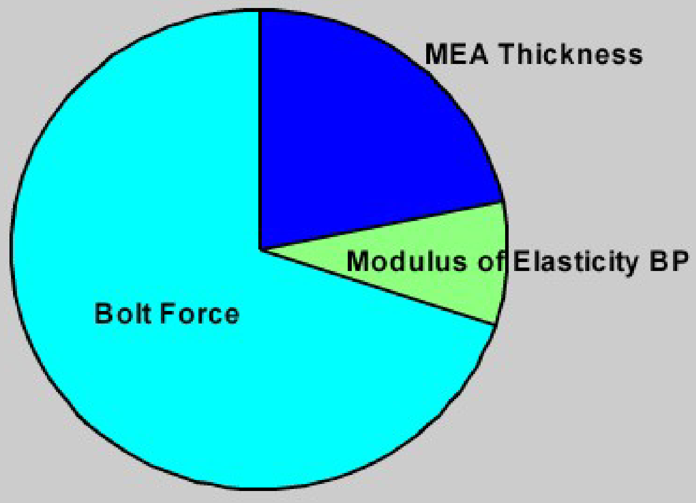
Sensitivity Analysis

- **Sensitivity of the design variables on the response attributes**
  - The bipolar plate thickness and the MEA thickness are the most significant factors on the top membranes' pressure uniformity
  - The bolt force, the MEA thickness and the modules of elasticity of the bipolar plates are the most influential parameters on the pressure uniformity of the MEAs in the middle of the stack

Sensitivity of Design Variables on Pressure Uniformity $\Delta\sigma_z$ of First Membrane



Sensitivity of Design Variables on Pressure Uniformity $\Delta\sigma_z$ of Middle Membrane



Conclusions

- MEAs' maximum compressive stresses are about 13% higher (case A) and 30% higher (case B) that the equivalent values of the middle MEA.
- The compliance of the "soft goods" of the first few cells provides uniformity in pressure distribution at the majority of the MEAs

•The bolt force, the MEA thickness and the modules of elasticity are the most influential input variables on the pressure uniformity of the MEAs in the middle of the stack